**Solar Photovoltaics: Principles, Technologies and Materials**
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**Lecture – 04**
**Effect of Location on Time**

So, welcome again to this lecture number-4 of the course on Solar Photovoltaics Principles, Technologies and Materials. So, we will just do a brief recap of last lecture.

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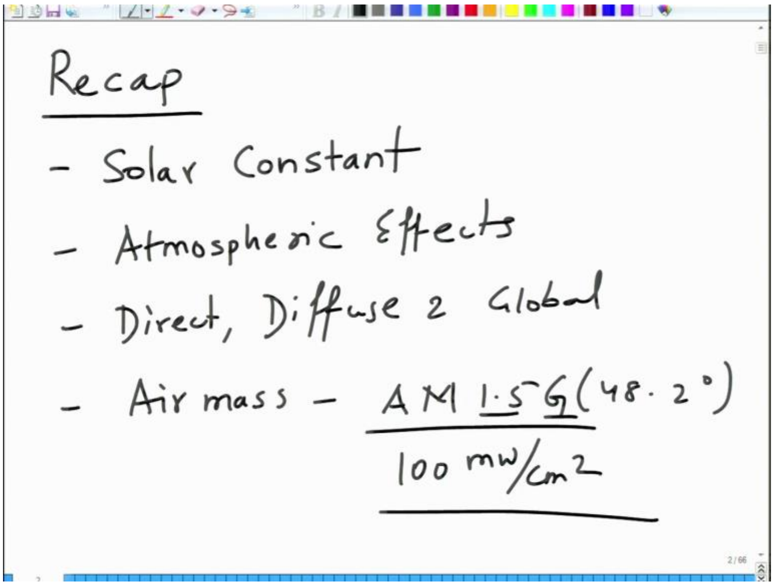


So, so in the previous lecture, we learned about what is solar constant basically how much is the energy which is received on the outer surface of atmosphere. And then we looked at what are the atmospheric effects which affect the intensity that you receive on earth on the horizontal plane. And then we also looked at the concepts related to direct, diffuse, and global radiation. So, direct radiation is the one which is directly in line with the sun with respect to the object, there is no deviation. Diffuse is the one which comes from the surroundings; and global is the sum of these two. And then finally, we also looked at air mass index which is essentially a measure of how much absorption the sun ray has gone into depending upon its angle.

So, you can have the sun ray coming at from zenith directly from top, it can come from horizontal direction, because the sun moves from east to west. And so when it comes it is at east, it is known that it is nearly parallel to the earth. And as it goes to the zenith, it is vertical and the beam comes directly onto the earth and then it goes to the west. Because there is a angular variation of sun's position with respect to earth, there is the amount of absorption that the beam goes through that atmosphere also changes because the path length is different.

As a result we need to standardize this. And the standard has come about to be AM 1.5 which corresponds to angle of about $48.2_0$ which basically averages out the overall rotation of sun throughout the course of the day with respect to solar panel. So, this is what we take during measurements as well. So, generally when you make measurements for a solar panels the value is taken as AM 1.5G and this is what it basically means.

So, it is basically 100 milli watts per centimetre square coming onto a surface which is sum of direct and global and diffuse radiation. G means global, 1.5 means corresponding to the average angle of $48.2_0$ which is the average intensity of the sunlight that should fall on a surface at a given time.

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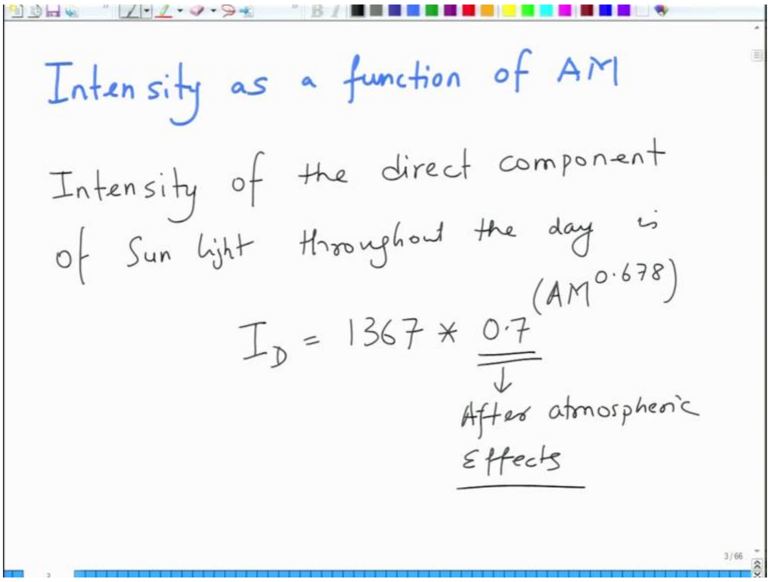


*Intensity of the direct component of sun light throughout the day is*

$$I_D = 1367 * 0.7^{AM^{0.678}}$$

Now, what we will do in this lecture is, we will look at aspects related to sun and the geometrical aspects of sun and earth. First we will just look at the expression of intensity as a function of air mass. So, the intensity of the direct component of sunlight, is basically with respect to the light, so light throughout the day is given as $I_D$ is 1367 which is a solar constant multiplied by 0.7 to the power AM to the power 0.678. So, this is the empirical equation. And this 0.7 factor is because of the fact that about 70 percent of the radiation reaches the earth, 30 percent is the it is lost. So, this is the 0.7 factor. This is really after atmospheric, we can see that if this factor was equal to 1, then this would be about 1367 into 0.7. So, whereas the 0.678 is an empirical fit to the data.

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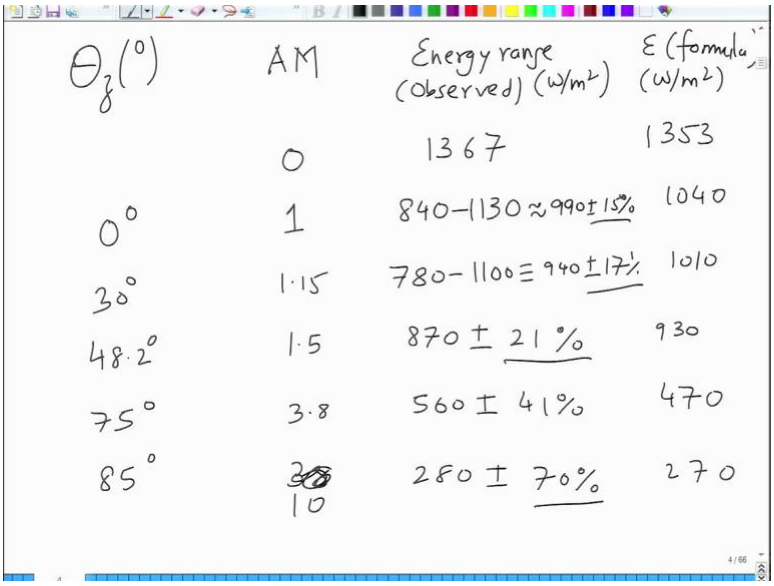


So, let me give you certain values now based on this. So, if you look at the intensity range, let us say $\theta_z$ value is varying here and let us say we take certain times to the day AM. And energy range which is observed and energy as per formula. So, if you look at the angle for example, at AM 0, it is 1367 and the value is also 1353 or so. And if you look at $0_0$ of $\theta_z$ and this AM is equal to 1 which is observed about 842-1130 which is about 990 plus minus 15 percent, whereas, the calculated value is about 1040, this is all what means watt per meter square .

And if you look at a value for example, let us say 30 degree, 30 degree gives you about 1.15 AM value. And this gives you a range of 780 to 1100 which is equivalent to 940 plus minus 17 percent. And we average the value that we calculate from formula it is about 1010 watt per metre square. If look at AM 1.5 which is 48.2 degree, so this is AM 1.5, we have variation of 870 plus minus 21 percent. So, this is energy range basically observed which is because of pollution. So, you have this much of variation. And the formula predicts the value of about 930 watts per metre square.

And if you go to higher angles, let us say about $75_0$, $75_0$ gives you 3.8. And this gives you a value which is 560±41 percent. And this is about 470. And if you look at $90_0$, this is 38. So let us say about $85_0$ , $90_0$ is parallel to horizontal which means nothing is coming onto the panel. So, we look at $85_0$- that is more realistic, $85_0$ gives you a value of about 10. And this is a value which is a 280± $70_0$ ,and the value that you get is about 270s.

We can see that the variation also increases as the angle increases, because the sun rays has to travel a long length as compared to the values which are coming directly out to the normal. So, when the path length increases, the unpredictability in the values also increase. You can see the error 15 % at $0_0$ , 17% at $30_0$, 21% at $48.2_0$ and this progressively increases to about 70% about $85_0$. So, when the path length of sun increases through the atmosphere, the error unpredictability in the value also increases, because the atmospheric affect become more and more stronger. So, smaller the atmospheric effects are, less better is the predictability of radiation.

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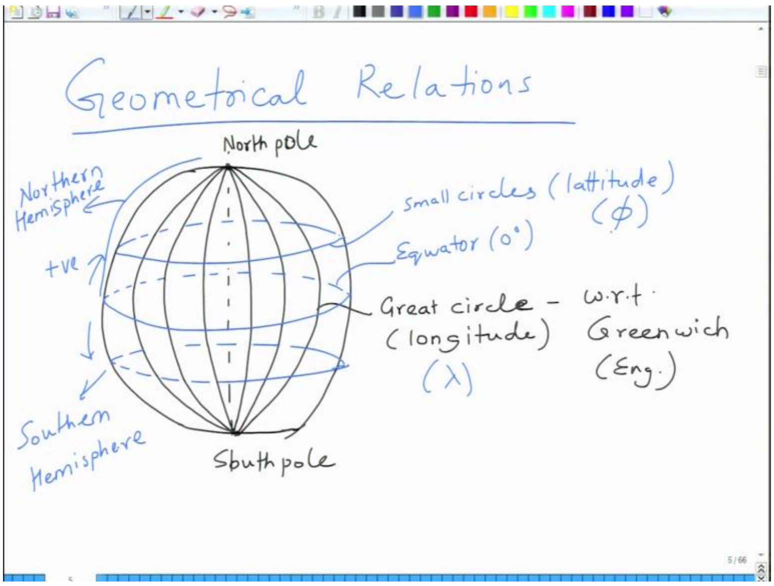


Now, we are going to look at the geometrical relationships. So, first and foremost, we are all aware of if this is our earth let us say. So, somewhere here you have North Pole; somewhere here we have South Pole. And these great circles are the once which are parallel to the vertical axis or these are basically great circles, the circles of equal diameter looked at various angles with respect to the north south axis. These are called as great circles. And they depict what we call as longitude. And longitude is measured with respect to Greenwich.

So, the measurement is made with respect to Greenwich which is in England. So, for England, the longitude would be to the start with 0 and then we measure the other locations longitude with respect to it. So, this is longitude. And the circles which you run horizontally they are called, as so at the centre the biggest circle, this would be the equator. And the ones which are running parallely these are called as small circles.

And these are called as latitude circles. And these LA double T I. So, these go, this way it will be positive and this way it would be negative. So, this would be $0_0$ latitude. On top of it you are closer to North Pole. And as you go in the bottom half, it will be in the south closer to the South Pole so, this is basically with the northern hemisphere and this would be your southern hemisphere.

So, Australia for instance would fall in some southern hemisphere. The South America would most of it would fall in southern hemisphere whereas some part of US, Africa bit also fall in southern hemisphere. Whereas, India and China and Russia and most of the Europe, all of the Europe and some part of Africa will fall above the equator that will be in the northern hemisphere. So, the relations of angles change depending upon whether you are in northern hemisphere or southern hemisphere, most of the calculations that we will do in this lecture are related to northern hemisphere, but there are some pluses or minus which come into picture when you deal with the northern hemisphere, southern hemisphere.

So, generally this longitude is depicted as lambda and latitude is depicted as phi. So, based on now we also know that since we measure our time with respect to the Greenwich mean time which is located in England. So, our time is 5.30 hours ahead of Greenwich mean time. Whereas, America would be some hours behind Greenwich mean time because the earth is rotating around its axis. So, the sun rises first and let us say in Australia or closer to Australia in the our east and then it comes to eastern nations, and then some light comes to India, Pakistan and then goes to Europe , but the reference is taken with respect to Greenwich mean time.

So, India is 5.30 hours ahead of Greenwich meantime. However, the time that we denote as noon does not necessarily mean that it is a solar noon. Solar noon means the sun should be on top. Whereas, according to our clocks the noon may be different. And this change has happened because of its eccentricity in the earth's orbit and various time zones and daylight saving notations that we have created and so on and so forth. So, when we make calculations of intensity we make time calculations, we have to be little bit more accurate than what we see in the watches.

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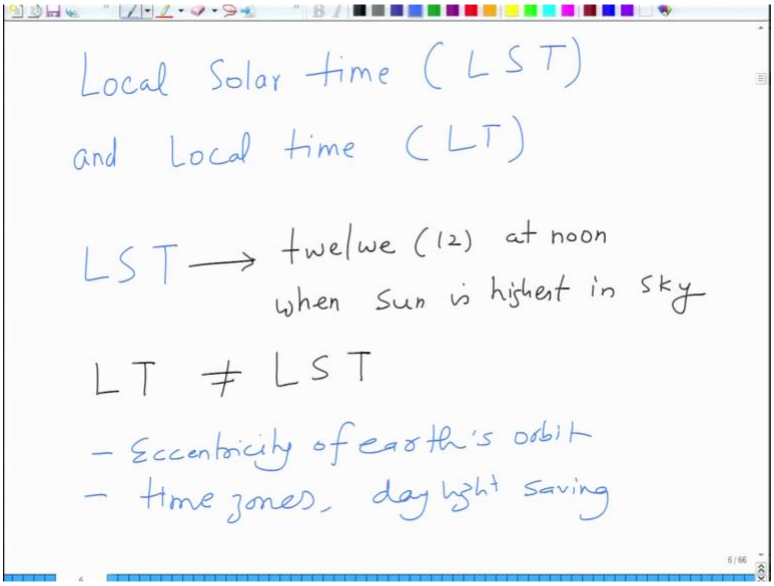


So that is why we need to have a distinction between what we call as local solar time which is called as LST and local time which is called as LT. So, local solar time basically implies 12 at noon when Sun is highest in sky. So, as per Sun's position that should be 12, but local time is not same as LST. So, LT is not same as LST.

So, what it means is that depending upon the time of the year, we can see Sun on the zenith let us say at 1 O'clock which is actually 12 according to solar time whereas in our watches at that time we will have 12. So, there is the difference of 1 hour, the sun reaches according to our watches, sun does not reach on the zenith at 1 pm, at 12 p m rather it reaches on the zenith at 1 PM or may be at a 11.50 PM . So, there is a difference between the local solar time which means when the sun is at zenith and the time in our watches.

So, we need to have some corrections for that. And these corrections are because of a eccentricity of earth and then we have time zones, daylight saving, there are some nations in which there is  daylight saving. For example, India does not have daylight saving, but many western nations follow this daylight saving especially in countries where day and night times vary significantly as a function of time of the year. So, to save the day light  they move their clocks by 1 hour ahead or behind depending upon time of the year.

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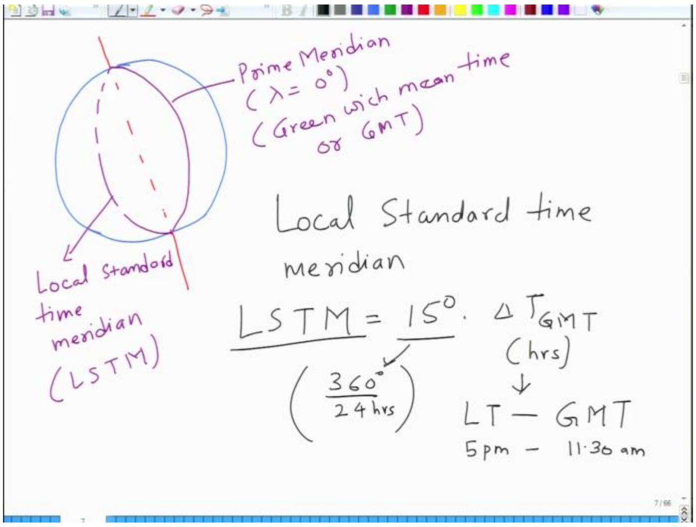


$$Local\ Standard\ time\ meridian(LSTM)$$
$$LSTM = 15^0.\Delta\ T_{GMT}$$

So, for this we need to make certain calculations. So, let us say this is earth. And this is the axis of rotation of earth. And on this we have some position marked as prime meridian which means lambda is equal to $0_0$ which is called as Greenwich meantime or GMT.

And the other one let us say a certain other location this is the local standard time meridian which is called as LSTM. So, local standard time meridian at the local place, local standard LSTM is essentially 15 degrees multiplied by delta T GMT. So, the time difference with respect to GMT in hours is equal to basically you can say local time minus GMT time ok.

So, if it is 5 pm in India, in England it is 11.30 am. So, the difference there is 5.30, 5 minute, 5 hours 30 minutes or you can say 5.5 hours all right. And $15_0$ comes from the fact that earth rotates $360^0$ in 24 hours. So, every hour it will rotate by $15^0$ ok. So, this is essentially nothing but 360 divided by 24. So, this is $360^0$ 24 hours. So, this is called as LSTM, that is local standard time meridian and basically we are calculating this in degrees angular values.

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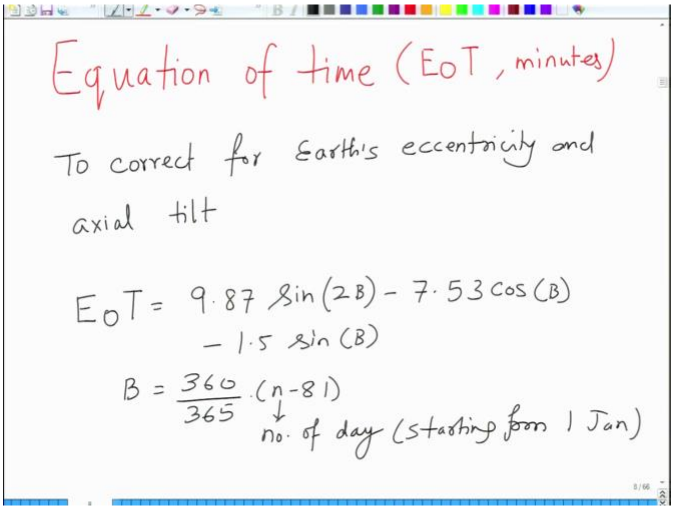


$$Equation\ of\ time\ (EOT\ in\ minutes)$$
$$To\ correct\ for\ Earth's\ eccentricity\ and\ axial\ tilt$$
$$EOT = 9.87\sin(2B) \ - \ 7.53\cos(B) \ - \ 1.5\sin(B)$$
$$B = 360(n-81)/365$$

n= no of days starting from January

And then there is something called as the equation of time, equation of time which is called as EoT in minutes. This is given as it is a empirical equation to correct for the eccentricity of earth’s orbit and axial tilt of the earth. So, to correct for and axial tilt, EoT is defined as 9.87 sine of sum 2B minus 7.53 cos B minus of 1.5 sine B, where B is 360 divided by 365 into n minus 81 , where n is the number of day starting from 1st Jan. So, 1st Jan would mean n is equal to 1.

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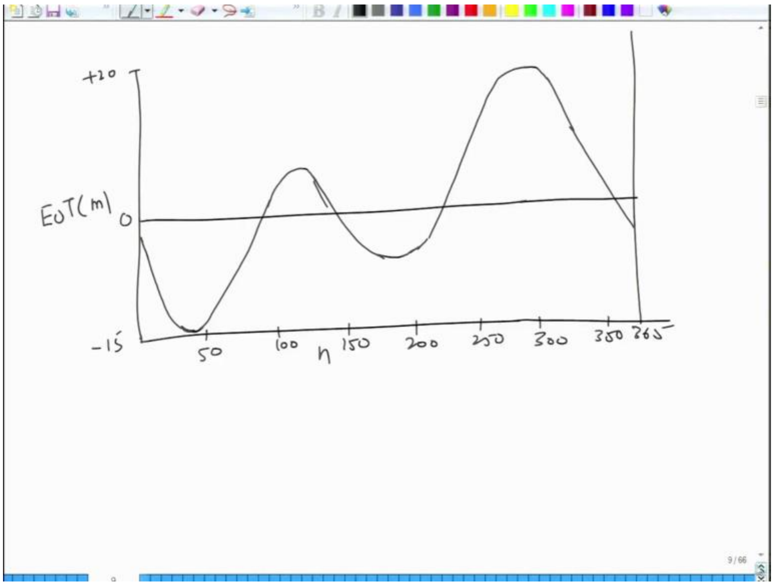


So, this shows a variation which you can plot, and we would not be able to plot it very accurately, but let us say if you plot it as a function of n and this is EoT in minutes this is 0. So, at certain values it would be let us say this is minus 15, somewhere here you have plus 20. So, let us mark certain values 50, 100, 150, 200, 250, 300, 350, somewhere here we will have 365. So, the way it will vary is it will go something like that. So, this is 50, 100, 150 and this is 365.

So, it will go as something like that. And then it will go to certain values between this. And then about 200 it will show a minimal, then again at 300 it will show sort of maxima and then come to certain. So, exact values we can calculate by putting the formula, but this is the variation it will show. For certain times of the year, the equation of time will run into negative and for certain times of the year the equation of time correction will be in the will have positive values. So, it depends upon the.

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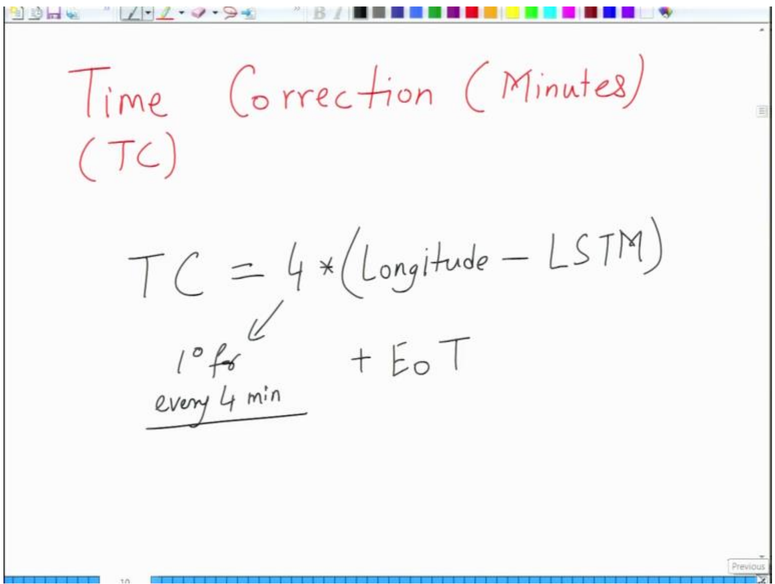

$$Time\ of\ Correction\ (TC)\ (minutes)$$
$$TC = 4\ *\ (Longitude - LSTM)\ +\ EOT$$

So time correction in minutes which is called as TC just given as so because of longitude variations and for a given time zone, we need to correct the time with respect to the local time. So, time correction TC is given as 4 into longitude minus LSTM which is, what we looked at first plus EoT. And this factor of four comes because you have 15 degrees per hour. So, basically every 4 minute you will have $1^0$ so, $1^0$ for every 4 minutes rotation.

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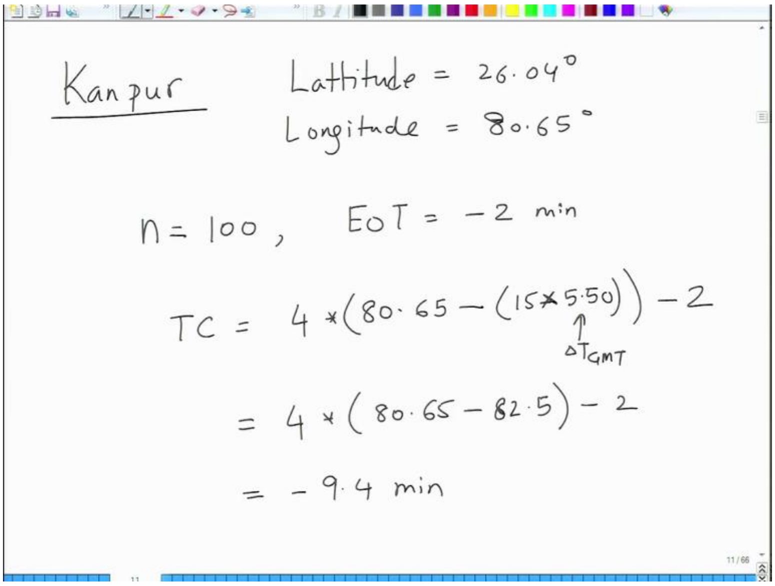


**Kanpur**

$$Lattitude = \ 26.04^0$$
$$Longitude = \ 80.65^0$$
$$n = 100: \ \ EOT = \ -2\ min$$
$$TC = 4 * (80.65 - (15 * 5.50)) - 2$$
$$= \ 4 * (80.65 - 82.5) - 2$$
$$= \ -9.4\ min$$

So, let us say if we do for Kanpur case, we are in Kanpur. Let us say, we have a latitude for Kanpur as 26.4 degrees and longitude of 80.65 degrees. So, let us say we take n equal to 100, so hundredth day of the year which will probably fall into April. And from this first we need to work out what is equation of time correction which we can get from this formula. So, we first calculate b by substituting the value of n and then we apply this in a formula that is above.

So, if we do it for Kanpur, we get EoT of about minus 2 minutes. So, time correction is 4 multiplied by 80.65 minus we said LSTM, LSTM is 15 multiplied by delta T GMT which is 5.50 right. This is delta T GMT. The difference of Kanpur with respect to delta T GMT is 5 hour 30 minutes.

Now, that is the whole India, but it would not be same for whole India because 5.30, five point, 5 hours 30 minutes is average for India, but we go to, for example, Rajasthan; Rajasthan is further west as compared to Manipur. So, Sun obviously will rise first in Arunachal Pradesh or Manipur than in Rajasthan. Similarly, Sun would set later in Rajasthan than it would set in Arunachal Pradesh. So, because of these variations in local variations in longitude and longitude values, we need to correct the time.

And this is equal to then what we have there. So, this is time correction 4 multiplied by longitude minus LSTM plus EoT and EoT we have worked out as minus 2. So, this will go as minus 2. So, if we do the math, so this is 4 into 80.65 minus 82.5 minus 2. And this will work out to minus 9.4 minutes. So, essentially the time correction on hundredth day of the year is minus 9.4 minutes, so which means that our solar noon is actually at something like 11.50 am instead of 12 pm. So, this is the time correction that we need to take into account.

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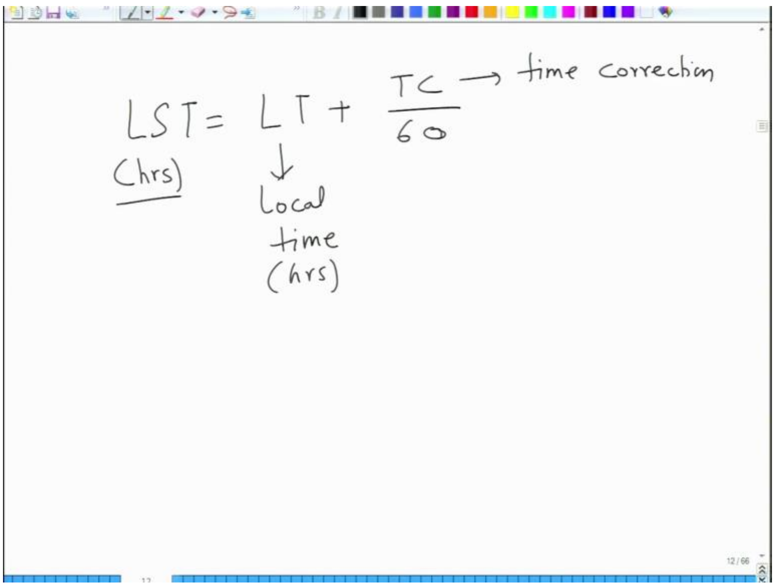


$$\mathbf{LST}(hrs) = LT(local\ time) + TC(time\ correction)/60$$

And so we can write this local solar time equal to basically LT plus time correction divided by 60. So, this is local time; this is time correction. So, this would be in hours, because we are dividing by 60. So, this is how we do the calculation of local solar time with respect to position at which solar panel is kept. So, this is what we have done so far. We have looked that this first geometrical relationship is the effect of basically time zone. We have not gone into geometrical relationships which we will cover in the next lecture.

Thank you.